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Tracking Generator for Microwave Ranges (1.7 to 13 GHz)

This article is part of a series, the other parts of the series will be published in issue 1/2001 of VHF Communications. This part of the equipment description includes the microwave ranges which are otherwise accessible only with commercial kit. Unfortunately, the processing of such a broad signal band can no longer be done entirely with low cost components. But the result provides a high-quality measurement assembly, giving laboratory quality operation from low frequencies to beyond the X band.

1.

Concept of UHF-VHF oscillator

The enhanced HP 8569(A) spectrum analyser forms the receiver section of a set of apparatus for network analysis. It can be used to control the frequency sequences, the range selection and the image display. Although the equipment dates back to as long ago as the first half of the eighties, all its good features can not really be developed in a DIY apparatus. However, other analysers (including those from various manufacturers) follow similar frequency concepts, so that the tracking oscillator presented here should also be adaptable for them. This network analysis process offers very great advantages over the classic wobble measurement.

The spectrum analyser has available an internal, frequency-specific local oscillator, this signal is available for external use on an SMA socket at the rear of the equipment. The frequency range of this YIG oscillator lies between 2 and 4.46 GHz; the level is maintained constant at 8 dBm. To create a generator signal on the analyser reception frequency, a fixed frequency at the level of the first intermediate frequency (321.4 MHz) is mixed in (Fig 1). Above approximately 4 GHz, it is really the various harmonics of this oscillator, arising during the mixing process, which take over the LO function during the mixing. An electronically tuned tracking filter, using YIG technology, cleans the other "signal waste" from the mixed product. A multi-stage broad-band amplifier raises the level of the filtered signal to a maximal 10 mW. The generator signal passes through a broad-band directional coupler which has a broad-band Schottky detector at its measurement output, this enables a constant output is maintained. A PIN attenuator adjusts the level of the intermediate frequency injection at 321.4 MHz. The automatic

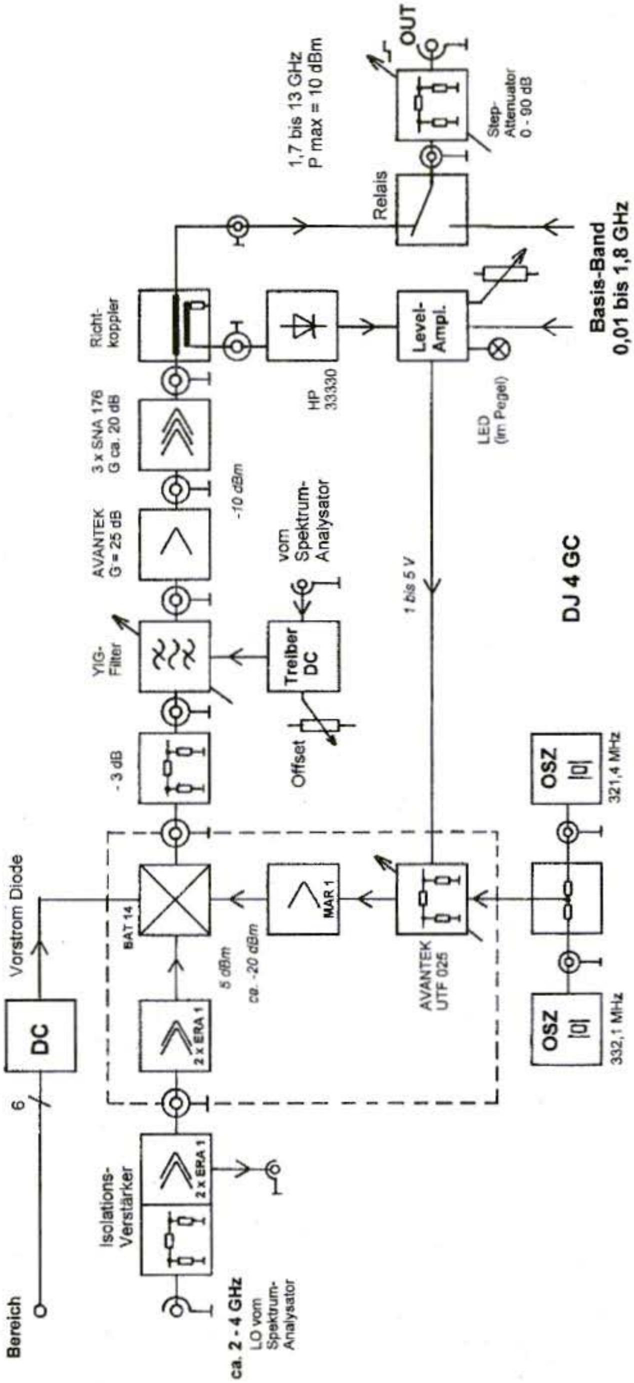

Fig. 1: VHF tracking generator concept

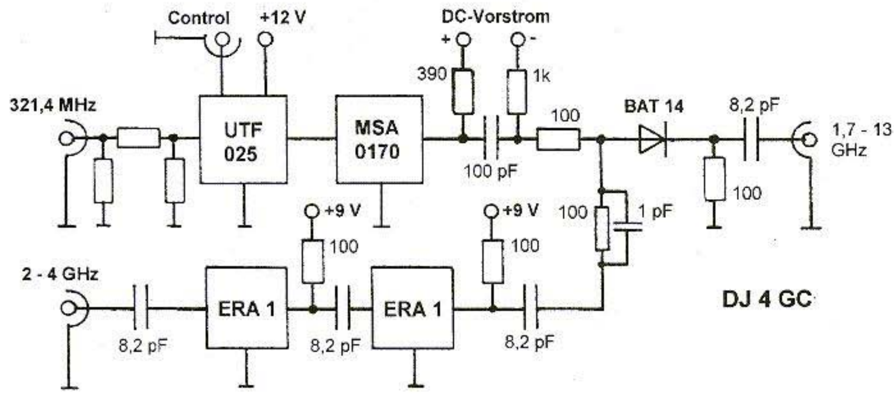

Fig. 2: Harmonic mixer with LO amplifier and level controller

level control, the buffer amplifier [1], and also the step attenuator at the output are used in common with the frequency synthesising of the basic band (10 MHz 1.8 GHz).

2.

Technical data of microwave generator

Frequency range of UHF-VHF section: 1.7 to 13 (15) GHz

Output level of generator: +10 dBm to 5 dBm, directly variable, plus 10 dB steps to 90 dBc

Amplitude ripple of generator: max ±1 dB in range from 1.7 to 13 GHz

Dynamic range of measuring system: min. 70 dB with 1 MHz reception band width, with reduced band width considerably more

Frequency noise: mainly dependent on LO of analyser; here so low that down to 100 Hz band width can be measured over the entire range

Output SWR of generator approximately 1.2 (return loss 20 dB) with 10 dB attenuation

3.

The assemblies

3.1. Harmonic mixer

The HP 8569 spectrum analyser goes up to 22 GHz in 5 frequency ranges which overlap each other to a large extent. In addition to the basic band processing from 10 MHz to 1.8 GHz, described in another part of this series, this home-made tracking generator covers the microwave range from 1.7 to 13 GHz without changing any high-frequency components. The microwave signal is processed separately from the basic band. From 1.7 to 4.1 GHz it is mixed with the fundamental frequency of the

LO signal which the analyser supplies. The second range (3.8 to 8.5 GHz) is produced by the mixing the first harmonic of the LO with the injected first intermediate frequency of 321.4 MHz. The third range (5.8 to 13 GHz) uses the third harmonic of the LO frequency as well as the intermediate-frequency generator at 321.4 MHz. At reduced amplitude, the mixed products reach as far as approximately 15 GHz before the YIG filter fails due to absence of current.

Attempts at signal processing with broad-band ring mixers have failed, since the even-numbered harmonics of the LO are severely suppressed, due to their symmetrical structure. The best mixed results were obtained using a half wave diode mixer with an individual microwave diode, a BAT 14 from Siemens (Fig 2). The required microwave harmonic in the diode current is optimised in each case using a DC biasing current which is adjusted, depending on selected range, to select the correct operating point of the diode. For each frequency range, the HP 8569 supplies a switch signal to a socket strip at the rear. From this signal the optimal diode biasing current can be obtained for the degree of multiplication in question (Fig 6). The adjustment is really critical, but can be carried out and optimised directly on the analyser screen.

The output spectrum after the mixing diode resembles a boiling inferno of harmonics and mixed products which makes it difficult to maintain a constant output level at the desired frequency. The spectrum analyser, with its internal YIG filter, has excellent selection characteristics, this technique could be used to help us get over the marked variations in level, but this requires considerable expenditure. A highly-selective YIG filter, locked into the mixing

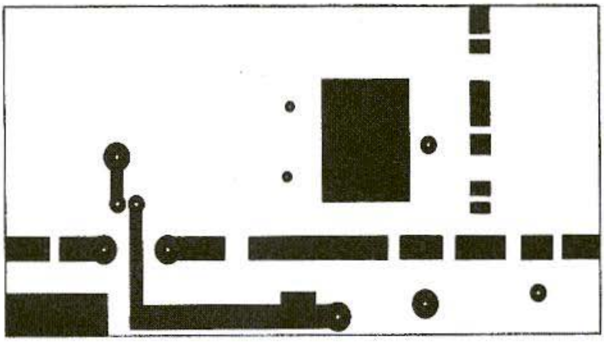

Fig. 3a: Harmonic mixer PCB layout. True size 71 mm x 35 mm

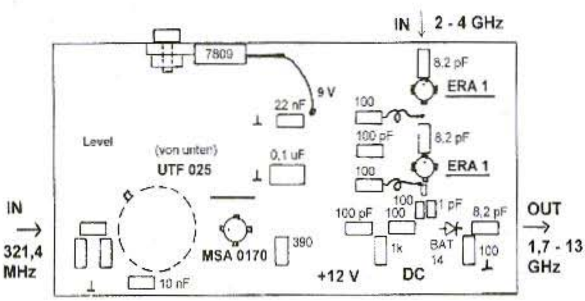

Fig. 3b: Harmonic mixer component layout. The PIN diode controller is on the earth side

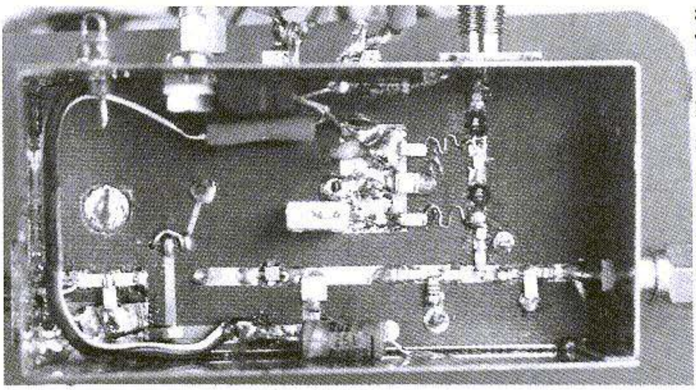

Fig. 4: Practical assembly of mixer. The output impedance of the 2-4 GHz LO amplifiers are supplemented by small additional inductances. These increase the amplification somewhat at the top end of the band.

frequency in question cleans up the signals before broad-band amplification and amplitude levelling take place.

Like a ring mixer, a half wave diode mixer also requires a broad-band termination, as real as possible. A matching amplifier would certainly improve the signal-to-noise ratio in the output spectrum, but is ruled out here because the LO bandwidth (2-4 GHz) is too high. Although further reducing the already limited mixed products after the diode (right down as far as -30 dBm) generates almost physical pain, a compulsory addition, in the form of an attenuator of at least 3 dB, must be inserted between the harmonic mixer and the YIG filter. Otherwise, due to reflections at the filter input, selective level changes, which can no longer be fully compensated, occur outside the transmission frequency.

3.2.YIG filter with driver

Both the main oscillator of the analyser and its pre-selector, as well as the locked-in filter in the tracking generator, are assembled using so-called YIG technology. The actual resonator is formed by tiny little balls (<1 mm, see Fig. 9) made from a mixture of the elements yttrium and iron, plus the semi-precious stone garnet. This mixture, which seems to have emerged from an alchemists

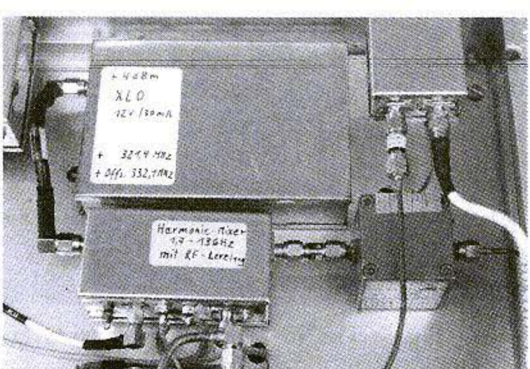

Fig. 5: Section of complete assembly with double XLO, harmonic mixer, 3 dB attenuator and YIG filter. The buffer amplifier for the 2-4 GHz LO is at the right-hand top edge of the illustration. More details of the layout of the two broad-band amplifiers will be in subsequent articles.

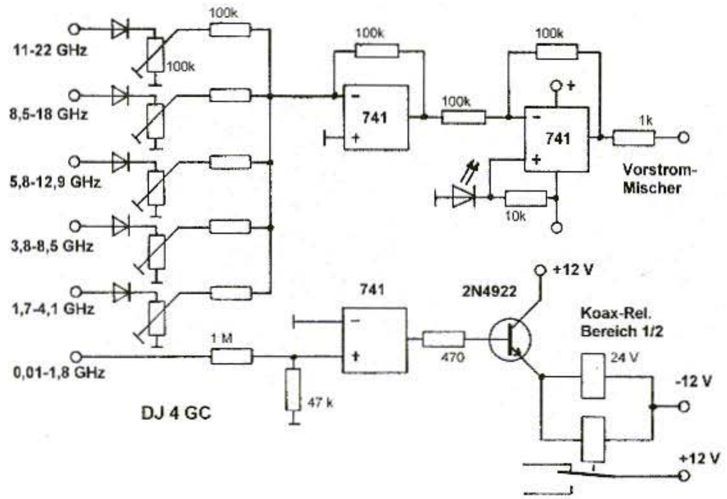

Fig. 6: Automatic biasing current generation for the mixer diode with the help of the turn-on voltages from the spectrum analyser. For range 1 (basic band up to 1.8 GHz), a coax relay switches the genertaor source.

kitchen, displays an inherent resonance in the microwave range when it is immersed in a magnetic field, this can be utilised by using a coupling loop. The level of the tuning current determines the resonance frequency by changing of the strength of the magnetic field. The filters, mainly two-circuit or four-circuit, combine high resonance quality (>1000) with very good isolation (up to 100 dB), a constant insertion loss (here approximately 4 dB) and massive tuning range. Measurements can be made from 1.7 to 15 GHz without any switchover, i.e. merely by altering the tuning current, thus for a first intermediate frequency at only 321.4 MHz, the mirror frequency attenuation will always exceed 80 dB.

The tracking pre-selector in the spectrum analyser generates the required tuning voltage from 1.7 to 22 GHz(!). The tuning voltage for driving the magnetising current is accessible at a socket strip on the rear of the analyser. The control voltage varies between 1.7 and approximately 15 V. Since a markedly linear relationship exists between the tuning voltage and the resonance frequency (1V/GHz), we need only an amplifier circuit which is able to convert the tuning voltage into a proportional current of up to 600 mA (Fig 8). The V-I converter developed for this measures the coil current indirectly as a voltage drop in a low-Ohmic wire

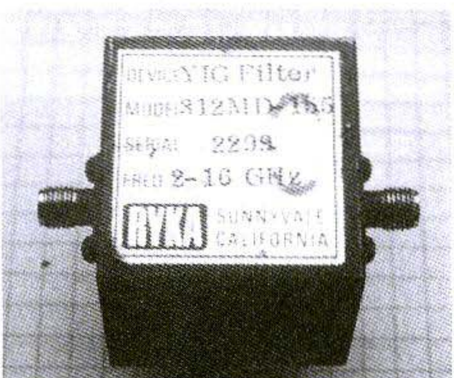

Fig. 7: The YIG filter for 2 to 16 GHz

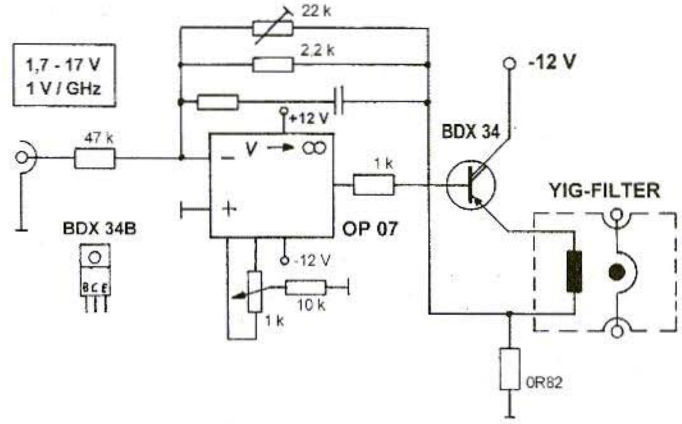

Fig. 8: Driver circuit for YIG filter

resistor, and feeds this voltage to the inverting input of a differential amplifier. Thanks to this little trick, the tuning current is not affected by either the higher temperature correction value, the marked heating-up of the copper coil, or their inductive effects. The V-I converter thus forces a linear tuning current through the YIG coil.

To de-couple the remaining assembly stages, the relatively high tuning current is drawn from the negative supply voltage. A PNP Darlington transistor (here BDX 34) functions as a load controller. Due to its high current amplification, it can be controlled directly by an operational amplifier. Because the YIG filter used here has an extremely narrow band, it is helpful to retain a small, externally adjustable offset variation. Despite the fact that the effect is only marginal, the use of a ten turn potentiometer is advantageous. YIG components should be mounted on a heat sink, or at least on a solid chassis plate, due to their high level of internal heating.

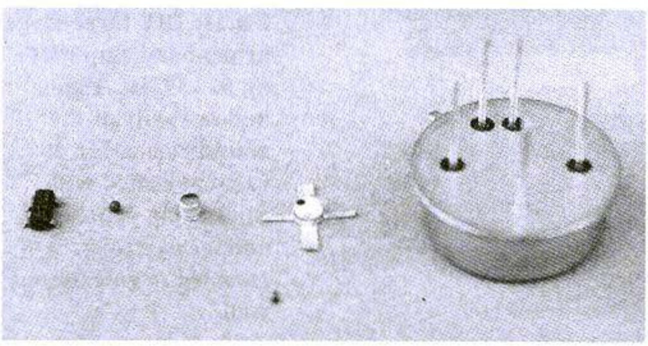

Fig. 9: Small component collection, from left to right: BAR 61 triple PIN diode, dismantled YIG resonator element, BAT 14 microwave diode, MMIC SNA 176 broad-band amplifier, together with UTF 025 PIN diode controller

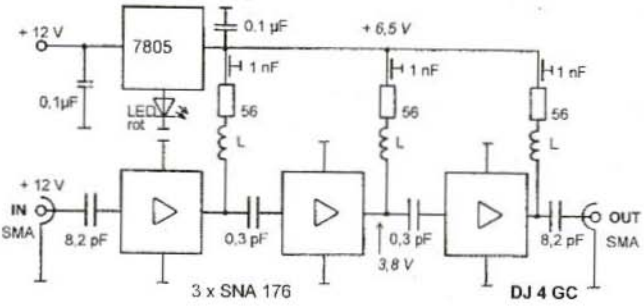

Fig.10: Circuit of second broad-band amplifier with 3 SNA 176s. In order not to overload the voltage reulator (I=50 mA!), the supply voltage was reduced to 6.5 V.

3.3. Broad-band amplification with level controller

The first of two amplifiers available was an Avantek broad-band amplifier (2-18 GHz) with G=25 dB. Mixing products can already be raised to above 10 dBm over the entire range using this commercial high-tech product. This level actually suffices for most measurements. The favourably-priced SNA 176 MMIC amplifier from STANFORD-MICRO-DEVICES, specified for use at up to 10 GHz, turned out to be an outstanding addition to improve the performance further. Three of these transistor-type SMD modules can be cascaded using very small coupling capacitors (0.3 pF) in such a way that an inverse frequency response takes place, giving a maximum gain of over 20 dB between 10 and 12 GHz and only then slowly decreases once more. If optimal matching is used, the amplification is approximately 10db at 2 GHz. This unconventional coupling can be used to offset at least part of the variations in the mixed attenuation between the basic and the harmonic mixing. With slight level compression, the

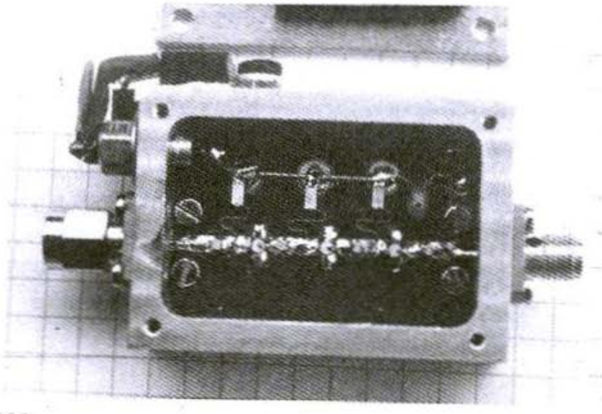

Fig.11: DIY three-stage broad-band amplifier up to 13 GHz. The hollow cavity of the amplifier housing is vacuum coated with conducting foam. The voltage controller is fastened to an external wall.

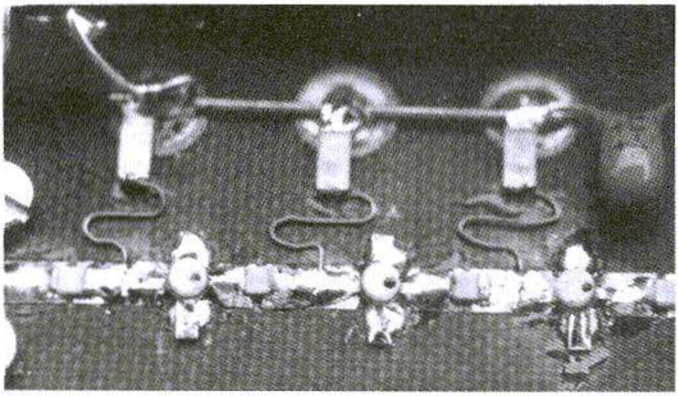

Fig.12: Details of this amplifier. The lateral earth connections of the MMICs are soldered to full tubular rivets; this leads to short earth paths and favourable heat conducting characteristics.

desired 10 mW output can still be attained at up to 13 GHz. Naturally, these excellent low-cost modules could also be used to provide all the amplification required.

The main level regulation is carried out before the harmonic mixer, by means varying the quartz-stabilised intermediate-frequency injection signal at 321.4 MHz. A commercially available monolithic UTF 205 PIN diode controller from AVANTEK adjusts the level prior to the high-frequency mixer in such a way that the pre-selected generator output is maintained at the output socket. The PIN diode controller described in [1], with the BAR 61 triple diode (in emergency, 3 x BA 379) could likewise do the job in a suitably modified printed circuit board design. This solution would be considerably more advantageous in terms of price, but would also take up a larger area than the commercial thick-film circuit in the TO 5 transistor housing. The OP circuit described in the first section is also used, as a control amplifier.

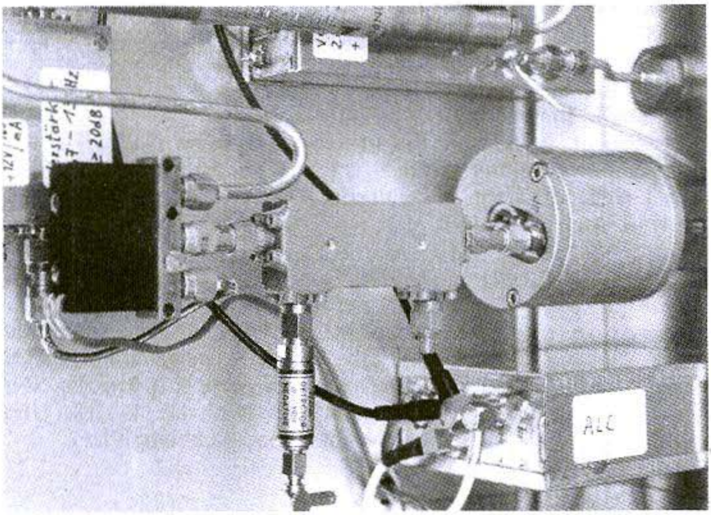

Fig.13: Section with coax relays, broad-band directional coupler, plus detector for level control (ALC), together with switchable attenuator in round metal housing.

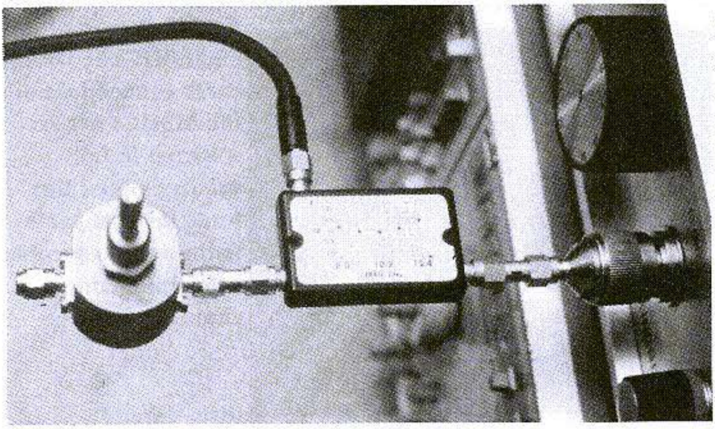

Fig.14: Matching measurement on an X-Band-Resonator brilliantly manufactured by DJ0PQ.

The actual value of the output level is established by a NARDA directional coupler (2-18 GHz, d=10 db, SMA connections), together with an HP 33330 B 50-Ohm detector. The level measured at the output socket (i.e. behind the step attenuator) using a thermal wattmeter are thus less than ± 1 dB from the set value over the entire range (1.7-13 GHz). Such good results can be obtained only if individual high-quality commercial components are used (such as directional couplers, detectors, Yig filters, etc.).

For measuring mixers, there is also a second intermediate-frequency oscillator available for the microwave range (321.4 MHz to 332.1 MHz). Depending on the apparatus, the offset variation of the YIG pre-selector in the spectrum analyser could be too small, so that it has to be expanded when it is integreated with the basic equipment. However, an oscillator offset reduced to, for example, approximately 3 MHz, could also solve the problem.

3.4. Commercial components

Numerous mishaps lie in wait for a generator project with a bandwidth of this order of magnitude. The noise level and, above all, the output control can not be any better than the components determining the level. My own experience suggests that you should not really try and conjure something up out of nothing and build as many components as possible yourself. Many inconspicuous looking little components contain so much unobtainable know-how that the entire project could rapidly turn into a permanent construction site.

The commercial high-frequency components used in the equipment described are listed below are mainly taken from surplus stock. Without them, it would have been considerably more difficult or even impossible to assemble the equipment. At all events, they contribute to the high quality of the finished apparatus.

Broad-band amplifier 2-18 GHz with G = 25 dB in housing with SMA connections AVANTEK AWT 18235

MMIC amplifier - monolithic SMD amplifier module with MAR and ERA range MINI-CIRCUITS wire terminating tabs or SNA range from STANFORD Microdevices, in particular SNA 176 (can be used up to 13 GHz, good-value broad-band amplifier)

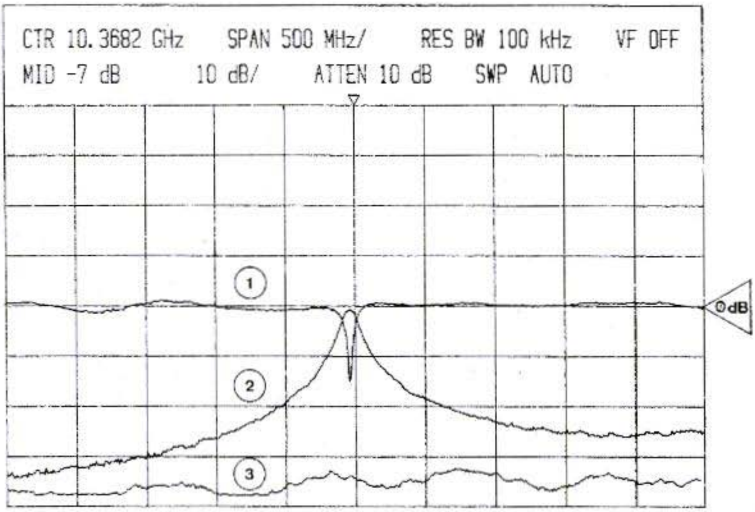

Fig.15: Measurement results for resonator from Fig.14. In the centre of this 5 GHz wide (!) frequency section lies the X-Band frequency of 10368 MHz. All measurement curves have been standardised to the screen mean (0 dBc).

1) Matching measurement using Wiltron coupler from Fig.17. In the non-optimised condition, the return loss amounts to 15 dB.

2) Advance measurement with approximately 1 dB transmission loss, together with remote selection to ±2.5 GHz.

3) Sharpness of directivity of measurement system with precision dummy on Wiltron bridge

Directional coupler 2-18 GHz with 10 dB uncoupling attenuation, NARDA 4203-10 SMA connections (for amplitude leveling)

Broad-band detector with Low-Barrier Schottky diode, 0.01-18 GHz, HP 33330 B APC 3.5 connection (SMA-compatible) (amplitude leveling)

YIG filter (microwave filter with electronically variable frequency) 2-16 GHz, made from old pre-selectors, generator systems, radar apparatus, etc., various manufacturers, for example AVANTEK, WJ, HP, OMNI-YIG, SIVERS, SYSTRON, VARIAN, YIG-TEK etc.

STEP attenuator, switchable attenuator in 10 dB steps, DC-18 GHz , various manufacturers (here WEINSCHEL AF 9010)

PIN controller, electronically controllable variable attenuator, thick film technology within the dimensions of a TO5 transistor housing (had one available, but good-value substitutes also conceivable) AVANTEK UTF 025

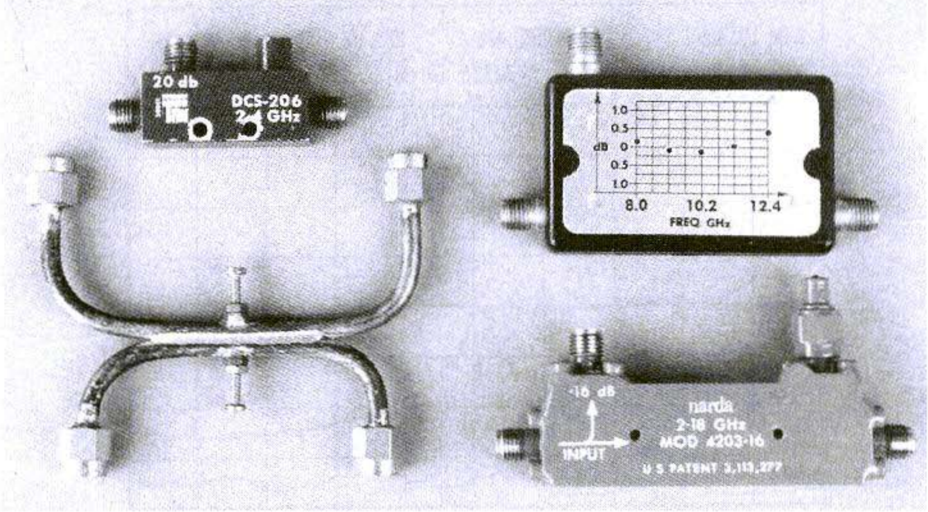

Fig. 16: A small selection from the options of directional couplers or adapter measuring bridges available

Additional small components such as SMA attenuators and a coax relay are the last things to go into the shopping basket. The list is the result of a pretty random search through electronics markets and second-hand dealers. There are undoubtedly many components from other manufacturers of comparable quality. While most individual components could be obtained relatively quickly and at reasonable prices, purchasing a broadband amplifier was a wearisome affair and it cost rather a lot of money. Actually, a high-quality DIY solution has appeared on the scene since then, the advantageously-priced SNA 176 MMICs from STANFORD Microdevices.

3.5. Directional couplers for the microwave ranges

For an efficient network analysis, directional couplers or adapter measuring bridges are required to determine the return loss within a 50-Ohm system. Fig. 16 shows a small selection from the options. Usually, the lower the band width, the greater the sharpness of directivity is. The extremely efficient DIY concept using semi-rigid circuits was described in greater detail in [2]. The SMA broad-band couplers (NARDA, KRYTTAR, OMNI-S-PEKTRA etc.) not exactly cheap even in a surplus market - with band widths of 2-18 GHz or even more, are usually optimised towards constant advance de-coupling for level controllers, which means the sharpness of directivity is of rather less importance. The coupler used in this tracking generator for power control (NARDA 2-18 GHz) continuously displays a sharpness of directivity exceeding 20 dB at up to 13 GHz.

Matching can take place over a particularly broad band with the help of measuring bridges. In principle, this refers to Wheatstone bridges suitable for high-frequency use, with a symmetry repeater for de-coupling in the bridge branch. The "queen" of measuring bridges, from WILTRON, is also structured according to this principle. The

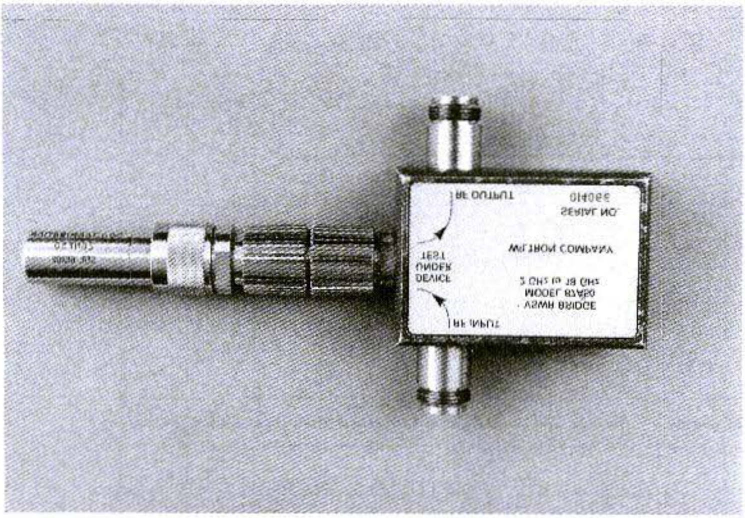

Fig.17: Wiltron measuring bridge with precision dummy as matching reference

measuring port is provided with a high-quality APC 7 connector, and must be correspondingly adapted in each case. Curve 3 in Fig. 15 gives a picture of its sharpness of directivity, which sets a new standard. The basic disadvantage of this (unfortunately scarce) component is its very high price.

3.6. LF transverter

The basic range of the spectrum analyser begins at 10 MHz. Below this frequency, loss of sensitivity and unwanted signals prevent any meaningful measurement. It is of little assistance here that the tracking generator described in another part of this article retains its level down to approximately 1 MHz. Unfortunately, this means that important frequency ranges such as low frequency, electronics applications, me-

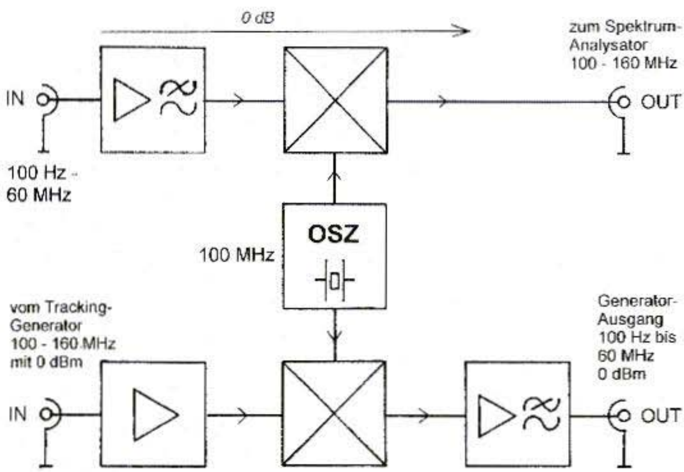

Fig.18: Simplified basic circuit of LF transverter

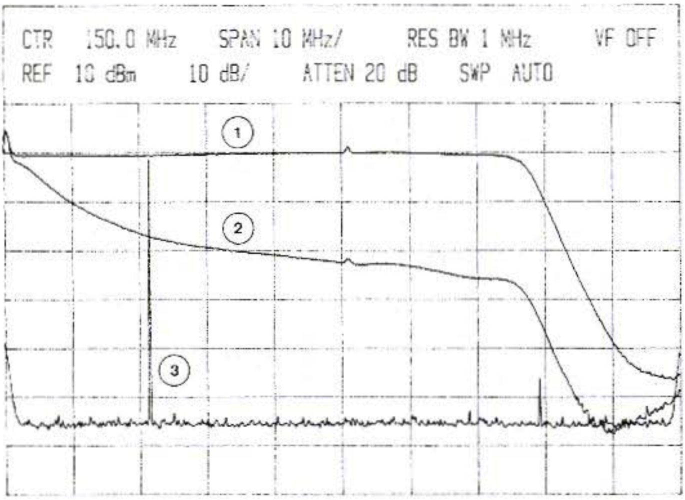

Fig.18: Efficiency of LF transverter from 0-100 MHz transposed to 100-200 MHz. The 100 MHz disruptive breakdowns recognisable at the left-hand and right-hand edges of the illustration are each represented as being as wide as the analyser bandwidth.

1) Frequency response record for entire measurement system. The tracking generator is coupled directly into the receiver input. From app. 75 MHz, strong level attenuation is noticeable as a result of the two low-pass filters. The ripple over the entire useful range from 100 Hz to 70 MHz is only approximately 1 dB.

2) Frequency response over high-ohmic impedance converter at app. half sensitivity. At maximum level setting, the curve is identical with curve1.

3) Noise level of transverter system, using example of a 21.4 MHz quartz filter.

dium wave or the lower short-wave range lie outside the width of the measurement system.

In order to close these unpleasant frequency gaps, a transverter has been developed which can go down as far as 100 Hz. In principle, both the analysis frequency and the generator frequency are displaced by exactly 100 MHz. As a result of this offset. the reception range on the analyser begins at 100 MHz. The tracking generator frequency is simultaneously mixed downwards by this amount. The 100-MHz quartz oscillator used jointly for both mixing processes allows the two frequencies to be equal.

The individual path within the apparatus from this oscillator to the mixer contains both high amplifications and good isolation. There should be at least 80 dB isolation between the two mixers, so that the tracking does not sneak around the test object on this path. The two 3-stage low-pass filters with a 3-dB limiting frequency, each of approximately 60 MHz, prevent the emergence of the 100 MHz oscillator signal, together with signal ambiguities resulting from image frequency problems and harmonics.

For simple level determination, the recieve converter is adjusted to 0dB transmission amplification. Since in the

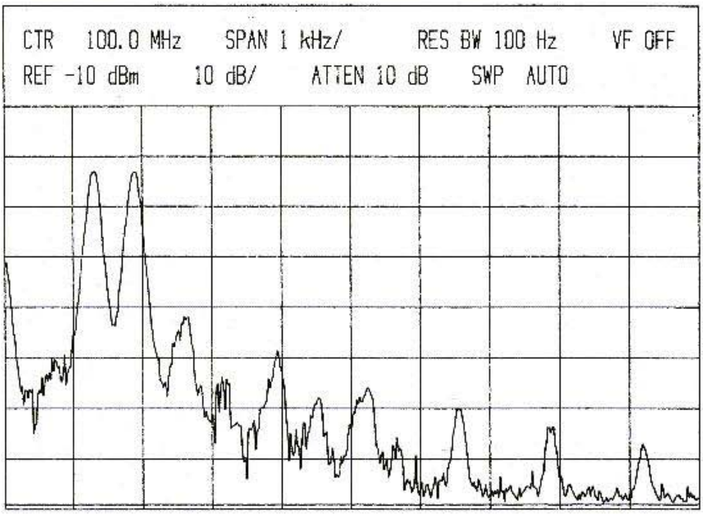

Fig.20: Spectrum analysis of a low-frequency two-tone (1.3 and 1.8 kHz) through transverter.

low-frequency and electronics ranges many signal sources are high impedance, i.e. may not be loaded with 50 Ohms, a high impedance converter with a sensitivity potentiometer is incorporated. The circuit, all in all is really extensive but otherwise conventional, is shown here only in outline, i.e. not going down to details of the solution. There are numerous alternative layouts, only suggestions for the creation of which are given here.

Even if the narrow-band analysis bandwidth of only 100 Hz is not optimal for the investigation of very low-frequency signals, the results are perfectly observable, even in the low-frequency range. Fig. 20 shows the spectrum representation of the low-frequency two-frequency generator, with which the author usually determines the inter-modulation products of transmitters and final stages. Each of the two tones on the left-hand edge of the image stems from a Wien bridge generator and gives a perfect sinusoidal optical display on the oscilloscope. Spectrum analysis shows that the interval between the lower of the two tones (1.3 kHz) and the first harmonic (d2) is a mere 30 dB. The harmonic

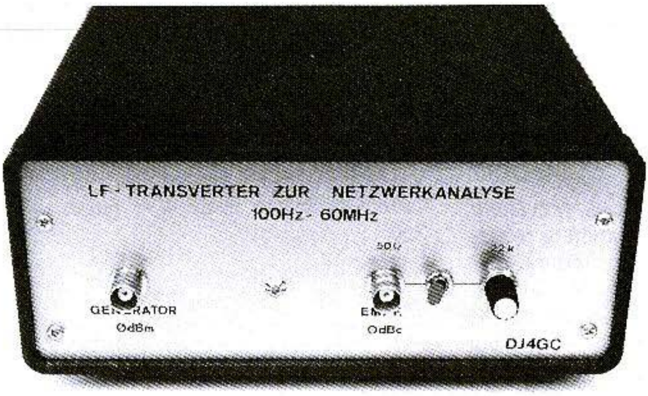

Fig.21: Complete low-frequency transverter.

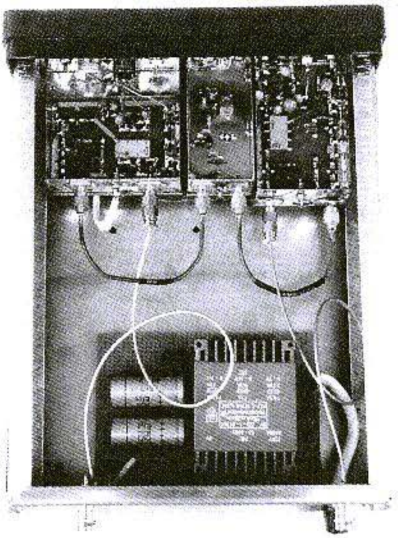

Fig.22: Internal structure with opened tinplate housings.

with the sevenfold frequency can also be recognised on the right-hand edge of the image, and the interval between it and the fundamental oscillation is approximately 55 dB. The rather unexpectedly poor harmonic interval of this generator, however, has only a slight significance in practical measurement, since from 3 kHz at the latest the transmission side filter forces the band to be restricted. The dreaded intermodulation products are mainly outside these filter bandwidths.

4.

Summing-up

By means of the accessories presented here (tracking generator, matching measuring bridge and LF transverter), the spectrum analyser, actually developed for the microwave range, is expanded into an efficient network analyser. The frequency range extends from the relevant range of FFT analysis with the sound card of a computer all the way to the wave guide bands. Including some quite long breaks, the project (excluding the LF transverter) lay on the hobby table for just on a year before it was fully completed. The test rig has now been operating satisfactorily for two years. The not inconsiderable effort (in terms of thought, manual labour and also money) has been rewarded, at the very least, with the availability of a laboratory-grade high-quality measuring system. Its really great when you don't just have to assume that something youve developed yourself works, but you can get the results displayed on the screen through a test rig with, as it were, infinite bandwidth and dynamism, while the plotter is already producing a hard copy.

5.

Literature references

[1] Carsten Vieland, DJ4GC. Tracking generator from 1 MHz to 13 GHz for spectrum analysers (Part 1 of this assembly description), VHF REPORTS, issue 1/2000 to be published in VHF Communications 1/2001

[2] Carsten Vieland, DJ4GC Microwave directional coupler with high front-to-back ratio made from semi-rigid circuits; VHF REPORTS, issue 4/1991, VHF Communications issue 3/1993 pages 130 - 139

[3] Joachim Danz, DL5UL, Assembly instructions and experiences with the spectrum analyser according to DB1NV; VHF REPORTS, issue 1/1993, VHF Communications issue 4/93 pages 241 - 250